The Origin and Evolution of the Universe

Question:

How do humans differ from other animals?

A: humans can speak;

B: humans can count;

C: humans use tools;

D: humans watch TV;

E: humans study astronomy;

F: humans pray to God;

G: humans can feel love (not just lust);

H: none of the above;

Scientific Method

- The difference between the science and the myth is that a scientific theory is based on *observations* and necessarily makes *predictions*, which again can be tested by observing the real universe.

- The scientific description should be *objective*, i.e. any observation or experiment should be *reproducible* by others.

Question:

How do scientists make science?

A: They sit in the lab/observatory and write in lab/observatory journals.
B: They walk in the park and occasionally smash themselves at the forehead and exclaim “Eureka!”.
C: They stand at the blackboard, talk, and scribble unintelligible symbols.
D: They sit at the desk and write pages and pages of dull text and long equations.
E: They stand in front of large audiences and make long and boring presentations.

GENERAL THEORY

INDUCTION
(from specific to general)

OBSERVATIONS

Specific instances

DEDUCTION
(from general to specific)

PREDICTIONS

Individual events

Scientific explanation must be:

- relevant (a pure thought does not work);
- falsifiable (this does not mean it is false);
- consistent with previously established theories;
- simple; this is sometimes called *Occam razor* (for medieval English philosopher William of Occam).
- predictive (not the same as falsifiable).

Question:

Which answer to the question
"Why does a pen fall on the floor?"
is falsifiable?

A: The Earth's gravity pulls it.

B: All things tend to move to the center of the Earth.

C: It just feels like doing that.

D: It is the God's will.

Levels of Scientific Truth

- **Law:** short, extremely well-established theory (usually a single equation).
- **Theory:** well established and well tested with the observations. All relevant quantities are known to sufficient precision. Rarely, if ever, wrong.
- **Model:** reasonably well established and tested with the observations. Not all parameters are determined to high precision. Rarely wrong.
- **Hypothesis:** plausible, but not well established; supported by a limited set of observations. Sometimes wrong.
- **Scenario:** quite speculative, supported by only a few observations, if any. Often wrong.
- **Paradigm:** a set of ideas, does not have to be supported by any observations. Usually un-specific.

Brief History of Cosmology from Aristotle To Newton

Ancient Greeks were the first to develop a *scientific* view of the world. They realized that it was possible to observe a natural phenomenon and to seek an explanation for it; it was possible to express this explanation in precise, mathematical terms.

The Greeks knew that:

- the Earth was a sphere;
- the diameter of the Earth was 250,000 stadia;
- But ***we*** do not know how much a stadia was (or, rather, there were several of them).

For the Greeks

mathematics = geometry.

The Greek world was made of straight lines, circles, and spheres.

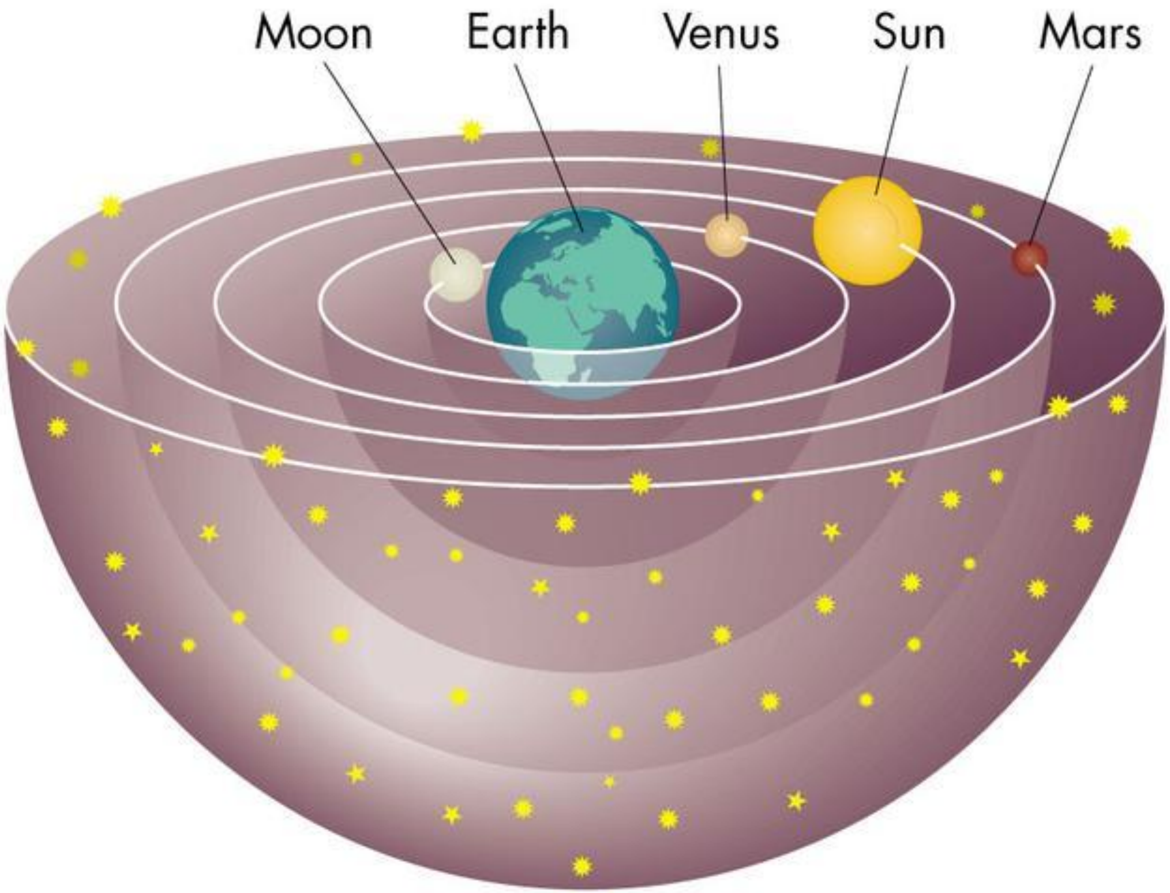
The Greeks considered pure mathematical thought to be supreme over the observations. The modern science is based on the opposite relationship (well, almost).

Eudoxus (410/408 – 355/347 BC)

(neither a sculpture of him nor his works survived to present)

- A student of Plato
- Believed to be the first to introduce geocentric (with Earth as the center) model of the solar system.

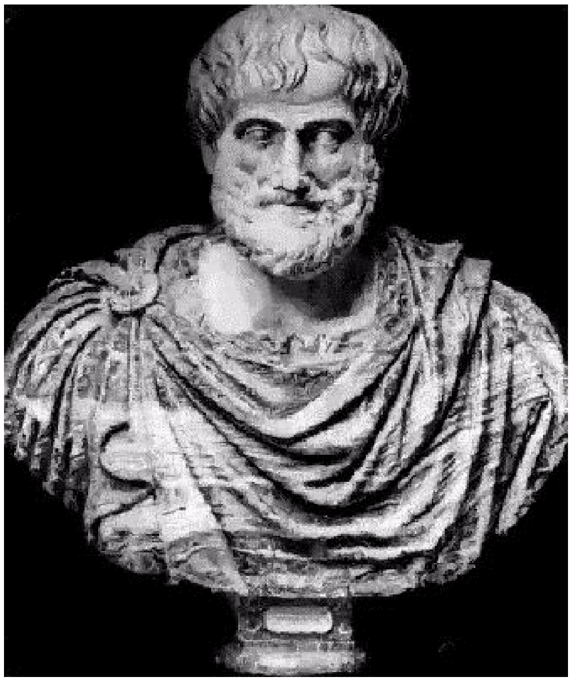
Geocentric model of the universe



Main Assumptions of Eudoxus's model

- Unmovable Earth is at the center of the world.
- The Sun, planets, and stars lie on rotating spheres.
- All stars are at the same distance from the Earth.
- There are 3 spheres for Moon and the Sun, 4 spheres for each of the 5 planets, and a sphere of fixed stars (27 celestial spheres altogether).

Aristotle (384-322 BC)



- Plato (Aristotle's academic advisor) thought that the observations are not important, perhaps even misleading. The pure geometry is the ultimate reality.
- Aristotle took observations seriously (but still he considered them inferior to the pure thought, more like servants of the theory).

Aristotle’s achievements

- Aristotle was the first to introduce the theory of motion, i.e. ***mechanics***, even if we now consider his mechanics to be wrong.
- He refined Eudoxus’ model: it now included 55 different spheres.

Aristotelian physics

- All earthly things consist of 4 elements: earth (rocks), water, air, and fire. They all move differently: earth goes down (i.e. to the center of Earth), fire goes up, water and air stay in between. Air bubbles go up in water, and rocks sink. Thus, the composition of an object determines the way the object moves.

- If let go, an object will move to the position in the world order predefined by its composition.

- To keep an earthly object moving, a force has to be applied to it constantly.

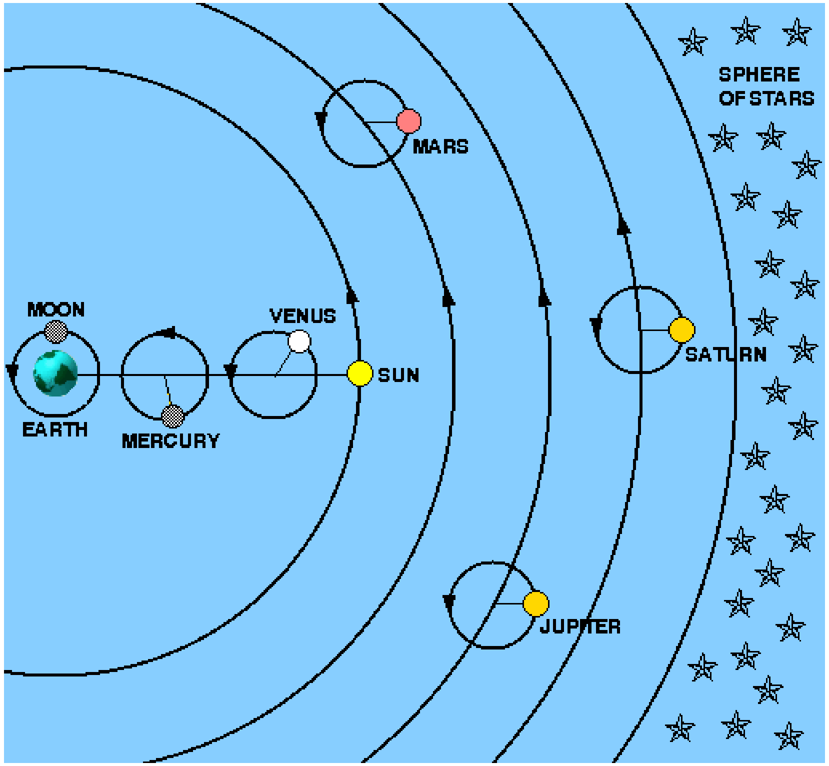
- Earthly objects move in straight lines toward or away from the center of the world, which is the center of the Earth. Objects move along this line with different speeds, depending on their composition.
- An object at rest (i.e. in its natural, predefined place in the world) will remain at rest unless is acted upon by a force.

- All celestial objects are made out of *ether*, the fifth element. Ether exists only in the cosmos, it is not present on earth.
- A celestial motion is perfect, it continues indefinitely without any force.

Ptolemy (100-170 AD)

- He completely reworked the Aristotelian world system. By his time astronomical observations improved so much that it became clear that the original Aristotelian system does not agree with them.

Geocentric model of the universe



Note: Sun always shines on Venus from behind

Fast Forward 1400 Years

1400 AD

Early Universities

University of Bologna	1088
University of Paris	1160
University of Oxford	1167
University of Cambridge	1209
University of Palencia	1212
University of Salamanca	1218
University of Padua	1222
University of Toulouse	1229

Portuguese voyages

- 1427: Azores (2,000 km)
- 1458: Gambia river (6,000 km)
- 1472: Niger river (12,000 km)
- 1482: Congo river (16,000 km)
- 1488: Cape of Good Hope (22,000 km)
- 1492: America (13,000 km over open water)
- 1497: India (38,000 km)
- 1522: Around the globe (70,000 km)

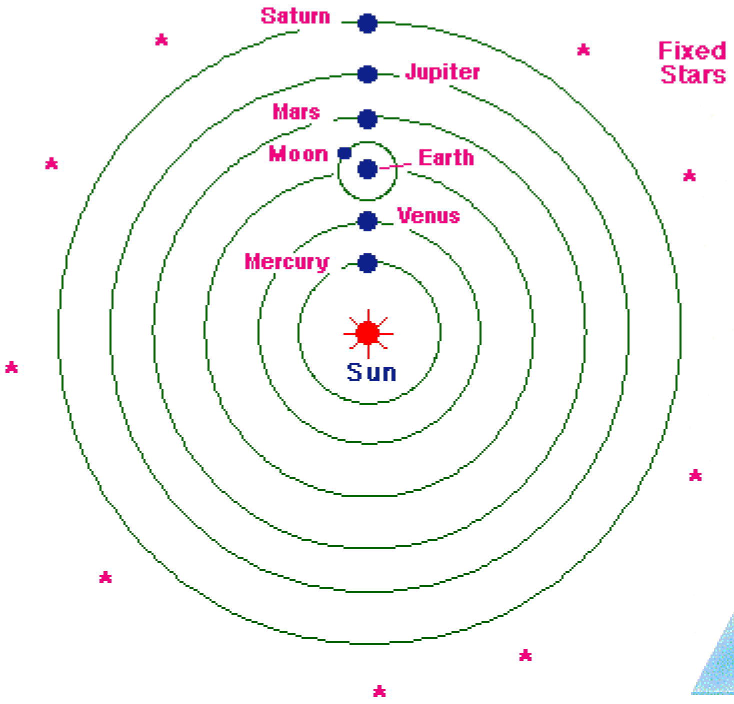
Revival of Astronomy

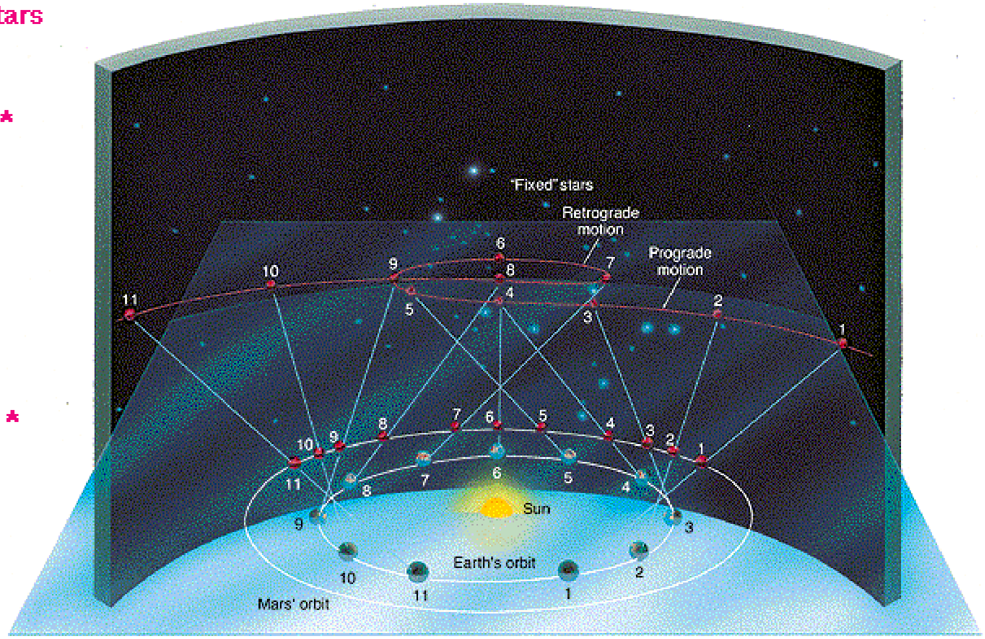
- Need for accurate navigation – precise prediction for astronomical events
- Printing press – wide spread of classical texts (Aristotle, Ptolemy) in authoritative editions
- Religious Reformation – fragmentation of Church, temporary softening of official Catholicism

Nicholas Copernicus (1473-1543)

(Latinized of Polish Mikolai Kopernik). He is credited with introducing the modern heliocentric model. We do not know what was his reasoning. Perhaps, he just wanted to light the world from the center!

Copernicus's heliocentric model





Big success

- Natural explanation for the retrograde motion of planets.
- Predictive power: a new planet should rotate slower than existing ones.

Tycho Brahe (1546-1601)

- He was a famous scientist and a heavy drinker (from which he might have finally died), which means that the two are not mutually exclusive.
- He repeated his measurements, i.e. made sure that his results are *reproducible*. Estimated the errors of his measurements; no one did it before him!

Ancient Greeks knew that

$$R_{\oplus} \approx 3 \times R_{\mathrm{m}}.$$

Tycho Brahe would write this as

$$R_{\oplus} = (3 \pm 1) \times R_{\mathrm{m}}.$$

A modern value

$$R_{\oplus} = (3.672 \pm 0.001) \times R_{\mathrm{m}}.$$

Johannes Kepler (1571-1630)

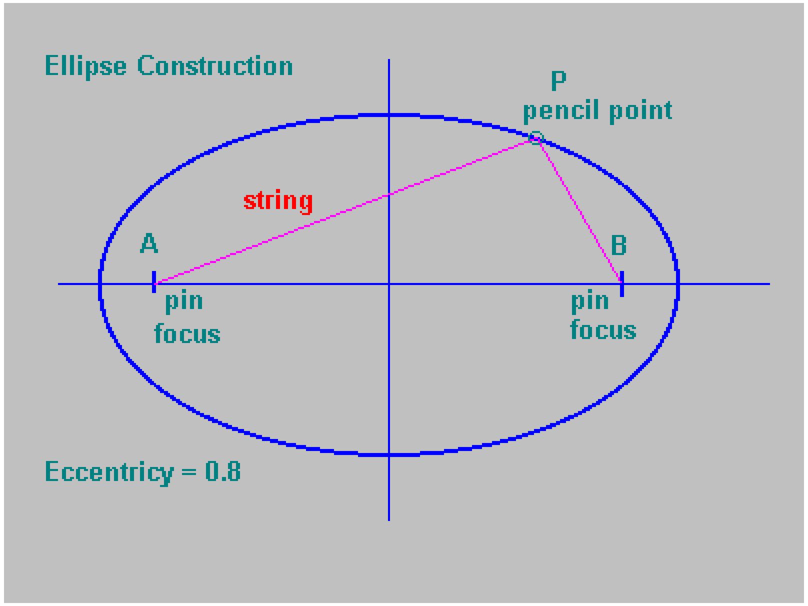
- He was an assistant to Tycho Brahe and inherited all his observational data.
- He lived in unfortunate times. He died in total poverty.

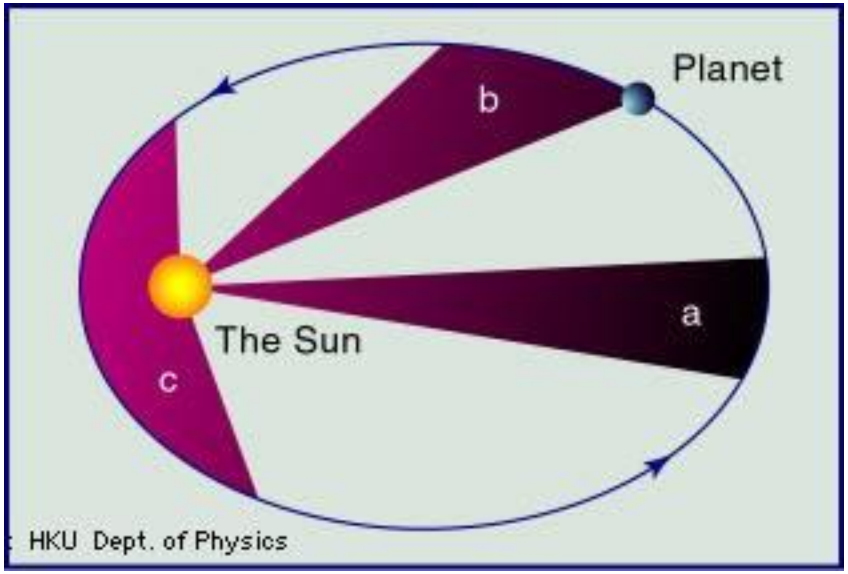
- He was faced with a serious problem: none of then existing models could fit the observational data to within Tycho's stated errors. He believed that Tycho calculated his errors correctly, so he embarked on developing a world model that was in agreement with observations.
- And then he had an inspiration!.. Not a circle but an ***ellipse***. A single ellipse with the Sun in its focus was able to fit all the data, instead of equants and epicycles in the Ptolemaic model.

Kepler’s Laws of Planetary Motion

- Planets orbit the Sun in an ellipse, with the Sun at one focus.
- The line from the Sun to the planet sweeps out an equal area in an equal time. Thus, planets move faster when they are nearer the Sun.
- The square of the period of the orbit is equal to the cube of the semimajor axis of the ellipse.

Kepler's first (left) and second (right) law



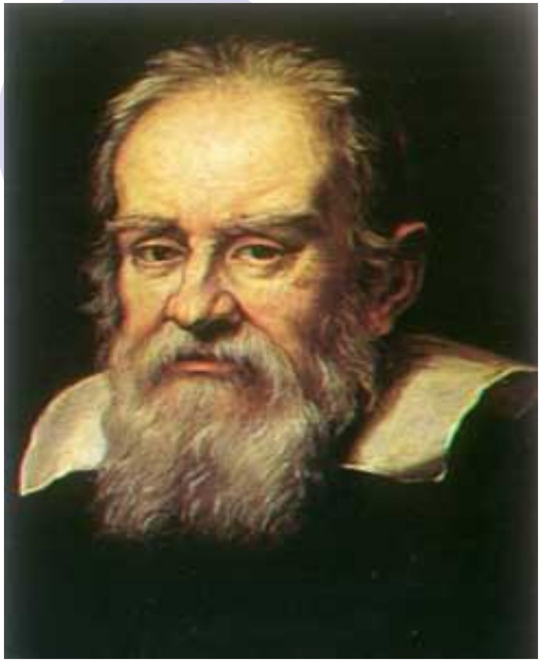


Kepler's third law

$$P^2 = R^3.$$

Very important note: This is only true if the period P is measured in years, and the semimajor axis R is measured in astronomical units. One astronomical unit is equal to the length of the semimajor axis of the Earth orbit.

Galileo Galilei (1564-1642)



Galileo…

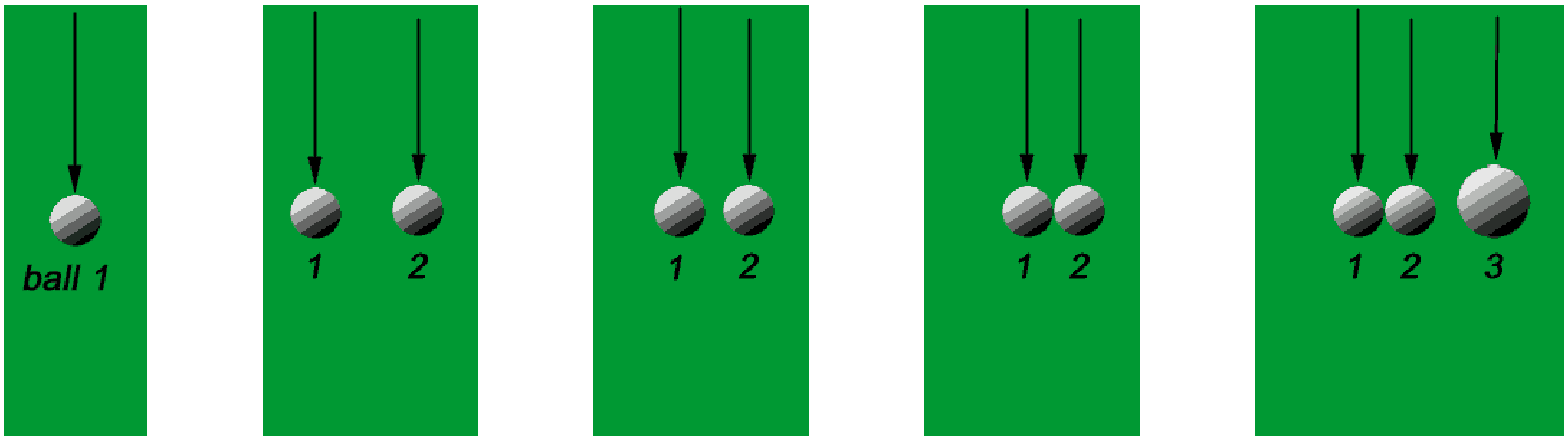
- did not dispel misconception that he was an inventor of the telescope;
- was the first to use the telescope for astronomical observations;
- ignored multiple pleas by Kepler to lend him a telescope or just a single lens;
- discovered that the Moon was not a smooth ball, but a world on its own, with craters, mountains, and lowlands;
- observed sunspots and calculated the rotational period of the Sun;

- However, his most important contribution was perhaps not in Astronomy, but in Mechanics. If the sky contradicted the Ptolemaic system, which was based on the Aristotelian physics, then perhaps the Aristotle's teaching about five elements was also wrong!

- He invented a *thought experiment*. He made some real experiments by rolling balls over a slide. However, he never succeeded in obtaining permission from the mayor of Pisa (who was concerned about the safety of pedestrians) to throw metal balls down the Leaning Tower.

- Galileo understood that if everything moves together uniformly, there is no perception of motion. In other words, moving uniformly is indistinguishable from being at rest. This understanding made the heliocentric model possible: the Earth moves, but we move together with it, thus not feeling this movement.

Galileo's Thought Experiment



1 big ball (= 2 small balls) should fall at the same rate as 2 separate small balls

Galileo and anagrams

- Galileo was fond of making ***anagrams***. That was also a way to claim the priority in a discovery without subjecting oneself to a danger of making a wrong claim.
- Discovery of phases of Venus he announced as
  - anagram: "Haec immatura a me iam frustra leguntur -oy" (*These immature ones have already been read in vain by me -oy*),
  - rearranged: "Cynthiae figuras aemulatur Mater Amorum" (*The Mother of Loves [= Venus] imitates the figures of Cynthia [= the moon]*).

Galileo’s story

- Galileo was a great scientist, but his life ended in misery. He was brought to trial for heresy in 1633, was forced to recant his scientific beliefs, and was confined to his home for the rest of his life.
- He died 8 years later, totally blind.
- Only in 1980 he was finally exonerated by Catholic Church.
- On Christmas Day of 1642, the year of Galileo’s death, Isaac Newton was born…